ADDRESSING THE IMPACTS OF WASTE ON OVERALL PROJECT PERFORMANCE: A STUDY OF APPLYING LEAN CONSTRUCTION PRINCIPLE IN PUBLIC WORKS DEPARTMENT (PWD), BANGLADESH

Submitted in partial fulfillment of the requirement for the degree of
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List of Abbreviations

Public Works Department, Bangladesh	PWDB
Public Works Department	PWD
BRAC Institute of Governance and Development	BIGD
Lean Construction	LC
Bangladesh Bureau of Statistics	BBS
Real Estate and Housing Association of Bangladesh	REHAB
Last Planner System	LPS
Bangladesh National Building Code	BNBC
Toyota Production System	TPS
Percentage Plan Completed Charts	PPC
Value stream mapping	VSM
Compound Annual Growth Rate	CAGR
Reinforced Concrete	RC
Reinforced Cement Concrete	RCC
Assistant Engineer	AE
Sub-Divisional Engineer	SDE

Abstract:

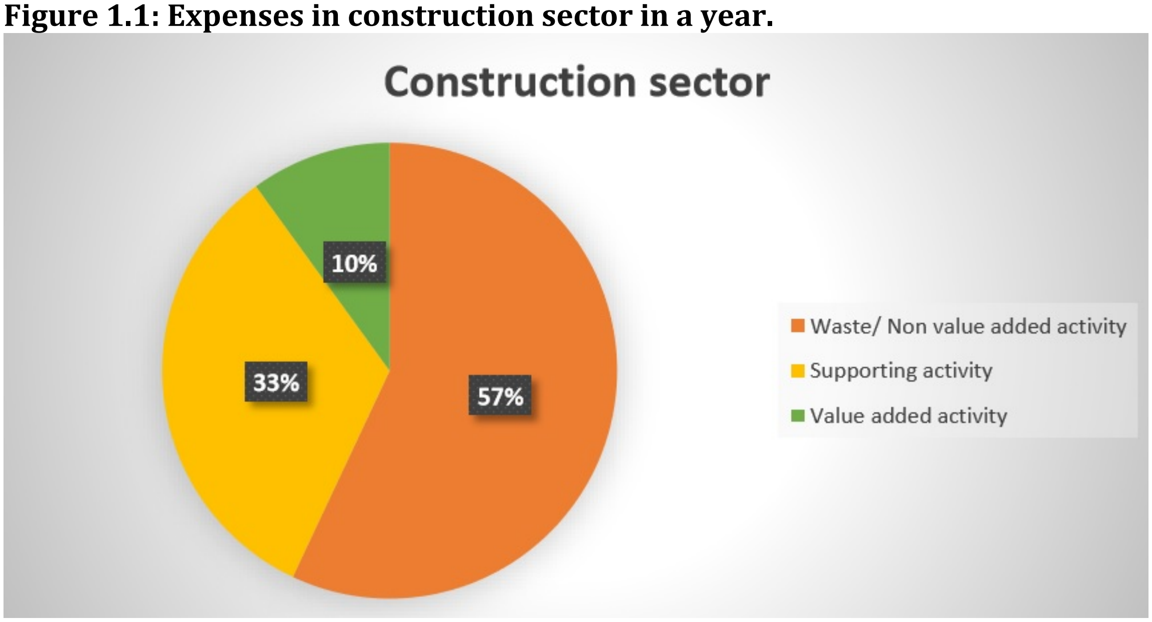
Presently, construction industry is under pressure and facing many types of problems. One of the major challenges is to reduce the waste during construction. According to Carlos Torres Formoso (1999), waste is considered as an inherent element in the construction process all over the world, Bangladesh being not an exception in this regard. However, success of a construction project is closely related to reduction in waste can be diminished. This study, focused on Public Works Department Bangladesh (PWDB),aims to identify key types of waste and examine its impact on overall project cost, time, quality, productivity and profit during the construction phase. It also examines feasibility of use of lean construction principle to reduce waste in order to enhance project performance. In order to fulfill these stated objectives literature drawn from journals, research papers, conference papers, books and credible web sources has been reviewed to describe root causes of waste and their impacts on projects. This theoretical explanation also put lights on the principles of lean construction and the benefits as a result of its implementation. Furthermore, an online based questionnaire survey has been conducted to fulfill the objectives of the study. The questions were asked on the basis of literature review and the majority of participants agreed upon seven possible types of waste (inventory, reworks, transportation, over processing, motion, waiting, and overproduction) generated in PWD's construction projects. Most of them said that waste exists 11% - 20% in construction projects under PWD. They were also asked to rank the root causes of waste along the magnitude based on their professional experience. According to most of the survey participants, the impact of the waste such as time over run from actual schedule of construction project under PWD is more than 12 months cost increase from the actual estimation due to waste is between 11% and20%. The respondents also reported construction quality disturbed, productivity loss and profit margin lost due to waste by 1%-10%. However, 90% of the participants agree that a new management approach/technique is essential to produce better results in the construction sector. Participants also ranked the lean principles on the basis of suitability. Finally, Recommendations are drawn from the study in order to enhance construction project performance.

Chapter 1:Introduction

1.1 Background study and motivation

Construction industries, everywhere the worlds suffer from several difficulties. “Waste” is taken into account as one of the chronic issues, which leads to low productivity, poor quality and large loss of money. According to Koskela (1992), waste is taken into account as any inefficiency that ends up in the use of equipment, material, labor or capital in larger quantities than those considered as necessary within the construction of a building. According to construction industry Institute, the construction project spends 57% of money on the non-value added activity in a single year that is taken into account as waste, while only 10% is spent for value adding activity (Figure1.1). Though this industry is extremely vital for any country, the rate of production within the construction industry lagsbehind manufacturing industries. The labor productivity within the total construction industry is negative 0.32% annually compared to positive 3.06% annually, in all non-farm industries (Teicholz, 2013).

Figure 1.1: Expenses in construction sector in a year.



Source: (David McNell, 2009)

Construction industry is not isolated from larger economy; rather it has influence on many industries in terms of purchasing inputs from other sectors. Waste can be generated at any stage of construction from design to utilization phase. Managing waste can save money and time, thus promoting larger socio-economic wellbeing of the society (GulPolat, 2004).

In order to increase productivity, several techniques and ideas were introduced in construction industries in the past decades. Prefabrication and modularization and computer integrated construction are two examples (Koskela L., 1993), where "lean production" is the latest addition (K. Agyekum, 2013). The main concept of lean production is the continuous improvement by eliminating non-value added activity or waste (Lee, 1999). With implementation this concept,many manufacturing companies have produced, the same quantity output using half of labor, cost, space, time and fewer materials than before. In 1992 after the formation of the International Group of Lean Construction (IGLC), the concept of lean was applied within the construction sector. Toexamine its impact on construction and productivity, several research works were conducted (El-Kourd, 2009). Using this philosophy, construction industry developedfinally a replacement concept of eliminating waste referred to as 'Lean Construction'. According to Koskela, Lean Construction is a way to design production systems to reduce waste of materials, time, and effort so as to get the most potential amount of value.

In light of this context, the present study aims to identify the key sourcesof waste and their impacts PWD's construction projects and examine feasibility of use of lean construction principle to reduce waste in order to enhance project performance.

1.2 Problem statement

The construction industry in Bangladesh has grown rapidly in recent years (REHAB, 2018). However, the adoption of the new ideas and technology are incredibly slow. This is commonly observed that the construction sector experiences severe drawbacks in terms of project delay and cost over-run resulting from many sorts of waste. Lack of communication, poor and absence of drawing, incomplete contract document, late decision making, high expectation, substandard planning and management approach, lack of skill workers, and political uncertainty may trigger the generation of wastes (Shaon, 2012). Public Works Department, Bangladesh is no exception in this case. To remain competitive, the PWD must exhibit productivity at the lowest possible cost and real time. In this situation, finding the root causes of waste and implementing strategies to reduce waste might be effective for improving construction project performance in Bangladesh, particularly in PWD.

1.3 Objectives of the study:

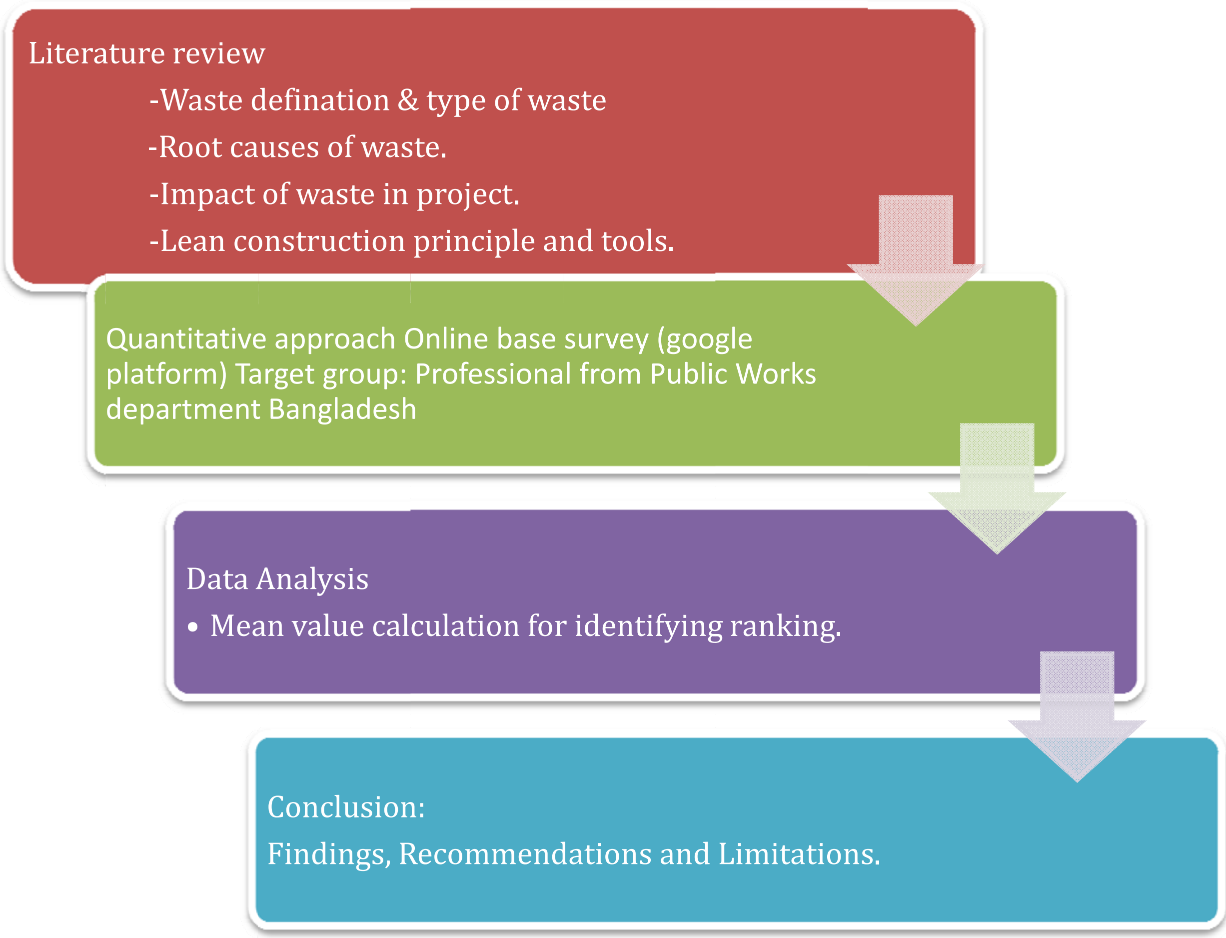
In light of the stated context and problems, the objectives of the present study are as follow.

- To identify the major types of waste in construction projects of PWD, Bangladesh.
- To measure the effects/impacts of waste in terms of cost, time, quality, productivity and profit during the construction phase.
- To determine the current appreciation and awareness of Lean Construction among the Engineers of PWD.
- To assess feasibility of lean construction principles in waste reduction and improvement of overall project performance within PWD.

1.4Research methodology

In order to achieve the stated objectives, a mix of literature review and questionnaire survey has been undertaken. Literature review was carried out to understand the causes of waste and their impacts in construction project, and waste reduction techniques specifically Lean Construction Principles. This review helped to frame research objectives and prepare questionnaire for survey among the professionals in PWD (Figure 1.2).

Figure1.2: Represents the flow diagram of research methodology of this study



1.4.1Questionnaire survey

An online based questionnaire survey will be administered among the selected respondents to assess the feasibility of introduction of Lean Construction Principles in PWDB to reduce waste in construction projects. The survey will also identify the root causes of seven kinds of waste generated during the construction phase and their impacts on the overall project performance in terms of cost, duration, quality and productivity. For the analysis of survey average mean value will be calculated using excel sheet and ranked according to the highest mean value.

1.4.2 Respondents and their selection process

The respondents for the survey are the professionals mostly Assistant Engineers (AE) and Sub divisional Engineers (SDE) of different working division, who were engaged in construction projects of PWDB. To select the respondents for his survey a convenience sampling method has been used due to time constraint and limited availability of the member of the target respondents. Accordingly, 25 AEs and SDEs were selected, focusing on the building projects inside the PWD. The selected respondents were sent survey questionnaire online; however, 20 respondents returned filled-out questionnaire.

1.4.3 Structure of the questionnaire

The survey questionnaire has four sections namely,

- Section A: deals with personal information about respondent.
- Section B: deals with root causes of 7 types of waste in construction projects.
- Section C: has question related to impact of waste on the project (in terms of cost, time, quality, and productivity)
- Section D: is structured on the basis of knowledge about lean construction and suitability in PWDB.

The survey questionnaire is given in Appendix A.

Chapter 2: Literature review

Construction industry itself is a complicated industry and is vulnerable to various kinds of waste. This chapter, based on literature, describes the various types of waste that occur in construction projects and their impact on overall project cost, time schedule, quality, productivity and profit. Furthermore, the common tools address waste related problems including lean construction technique and its main principle are discussed in this chapter. At the end of this chapter benefits of using lean construction techniques, based on past research are presented as well.

2.1 Construction industries

Construction Industry is one of the most booming industries in the world. This industry is mainly concerned with preparation as well as construction of real estate properties which take place mostly in urban areas. The repairing of any existing building or making certain alterations in the same also comes under Construction Industry. This industry can be classified into three basic categories namely (Economy Watch, 2010):-

i. Construction involving heavy and civil engineering:The construction of large projects such as bridge, road, etc. comes under this category.
ii. General construction: This type of construction works involves building of real estate such as residential or commercial real estate assets, etc.
iii. Construction projects involving specialty trades: These are construction works that involve building of specialized items namely, electric related works, works on woods, etc.

According to Luncintel market research report (December 2017), the future of the global construction industry omens good with the growth in the development of residential and non-residential infrastructure. The global construction industry is expected to reach an estimated US $10.5 trillion by 2023, and it is forecast to grow at a compound annual growth rate (CAGR) of 4.2% from 2018 to 2023. The growth of this market is growing due to increasing urbanization and population growth. Along this growth, some emerging trends have a direct impact on the dynamics of the construction industry. They include increasing demand for green construction to reduce carbon footprint, bridge lock-up device systems to enhance the life of structures, building information systems for efficient building management, and the use of fiber-reinforced polymer composites for the rehabilitation of aging structures (Luncintel, 2017).

2.2 Bangladesh construction industries

Bangladesh has recently reached lower-middle income country status which is expected to grow to a middle income country by 2021. Reaching this goal requires infrastructure development and more housing facility to the citizen of that country. In keeping with the pace of economic growth, construction industry is growing fast in Bangladesh. According to REHAB (2018), 3.5 million people work in the construction sector in Bangladesh. The GDP contribution of this sector is 7.98%, equivalent to 1,698,550 million BDT in FY 2017 – 2018 (Bangladesh Bureau of Statistics (BBS), 2018).

There are three stakeholders involved directly in construction industries namely, clients, consultants and contractors. The client is someone who invests the money on the project. In Bangladesh, mainly two types of clients exist who are public works and private works owners. Government is the main client of public projects and these include the entire public infrastructure such as roads, bridge, national hospital and many other public buildings. A private owner invests money on the project by taking loan from the bank or any other source with the aim of getting profits through selling the infrastructure to market. Private real-estate business is an example. Consultants are responsible for the overall design of the projects in both public and private sector. They are mainly architects, structural engineers, geodetic engineers, plumbing engineers, electrical engineers, and so on. Finally, the contractors execute construction works. There are also many categories of contractors such as civil contractors, plumbing contractors, electrical contractors and so on (BNBC, 2006).

Generally two types of construction are common here i.e. reinforced concrete (RC) structure and steel structure. However the amount of steel structure construction is very lower compare to RC structure. Prior to construction work, a contract paper or agreement is signed between two or more parties generally between an owner with a contractor or design team where the latter agree to provide services to the former in exchange monetary profits (Cherf, 2015). In Bangladesh, generally contract is prepared based on any of three modes namely fixed price or lump sum, unit price, and actual cost plus fee.

Planning is a very important part of any construction project. Cherf (2015) argues that "Without a plan, there is no way to schedule the required work, no way to track progress, and no way of deciding on corrective action when unexpected events occur". In Bangladesh two types of planning techniques dominate the construction projects which are bar chart or Gantt chart and network analysis (CPM, PERT).

2.3 Waste in construction projects

Waste in the construction industries has been the subject of research projects around the world (Formoso, 1999). According to Skoyles (1987) in his study in the UK mention that all the party involved in construction process from designer to the site supervisor contributed to waste. This includes. It is also their responsibility to minimize waste (ibid).

From the client point of view, waste can be defined as any losses produced by activities, which are responsible for generating direct or indirect costs but do not add any value to the products (Carlos Torres Formoso, 1999). In general, waste can be defined as an activity that consumes resources (money, manpower, time, materials) without adding any value to productivity. According to lean philosophy, waste is termed as non-value added activity (Koskela, 1992). Polat defines waste in a simple way, waste is "that which can be eliminated without reducing customer value" (GulPolat, 2004).

Again non-value adding activities are two types. The first one considers as an incidental support act, which means the activity does not add value to the customer, however, needed for the progress of the projects. Examples include drawing and standard development, order or invoice processing, waiting, setting of concrete forms, etc. On the other type of non-value activity is pure waste, which are completely unneeded and does not add any value to project progress, such as unnecessary movement of workers, re-works due to using the wrong technique and tools and so on (Chua, 2003).

2.3.1Classification of waste

Waste is classified in many ways. According to Formoso (1999), waste can be classified as unavoidable waste or natural waste and avoidable waste. Aziz (et al., 2013) classify

“Anything different from the absolute minimum amount of resources of materials, equipment and manpower, necessary to add value to the project”. Nagapan (2011) classified waste into two major groups, namely the physical and non-physical waste. Physical waste is the mixture of inert and non-inert materials that arise from construction; and non-physical waste indicates intangible waste such as cost over-run, time over-run. Al-Moghany (2006) explained construction waste by dividing into two types: material waste and time waste. Waste also may be categorized according to its source where the main cause of waste occurs. It may occur from any processing stage such as material manufacturing, training to human resource, design, material supply as well as planning (Formoso, 1999). In their research Bossink and Brouwers (1996) classify the source of waste according to causes of waste, which are design, procurement, material handling, operation, residual, and so on.

Shingo (1989) identified seven types of waste in construction –namely,

I. Re-works or defect.
II. Unnecessary inventory.
III. Transportation.
IV. Over processing.
V. Waiting.
VI. Motion.
VII. Over productivity.

2.3.2Factors that cause various types of waste

There are many factors that are responsible for generating the stated seven types of waste. These factors are categorized according to wastes:

I. Inventory

Inventory waste refers to supply of excess materials and goods, which are not required immediately. However, not all the inventories are waste, sometimes it can be utilized for quick build-up. This excess inventory also required extra space and additional handling (Gatlin, 2010). Inventory related wastes are generated due to poor method of storage facility in site, lack of control on material in the construction site, damage of material caused by deficient stockpiling and handling of material, and deficiency in detail about the material properties and dimension in the working drawing (El-Kourd, 2009; GulPolat, 2004).

II. Rework/defect

Defect or re-work refers to works, which are not done correctly or as per specification. This kind of waste will also result in loss of time, money and material. Rao (2014), Agyekum (2013), GulPolat (2004), and El-Kourd (2009) found nine factors causing re-work or defect related waste. Theyinclude (i) labor mistake; (ii) insufficient instructions about handling; (iii) choice of wrong construction method; (iv) subsequent trade contractors; (v) using faulty construction equipment; (vi) lack of interaction between labor and engineer; (vii) imperfect planning of construction; (viii) lack of workers' skill; and (ix) use of the wrong material.

III. Transportation

Sometimes waste is generated due to redundant movement or motion of materials or product which does not support to immediate production. This kind of waste creates unnecessary inventory and material damage (Gatlin, 2010). The factors that cause transportation related waste include far distance between place of working and storage, use of whatever material very near to theworkplace, unpacked supply and unnecessary material handling and movement (El-Kourd, 2009; Ekanayake, 2000).

IV. Over processing

This kind of waste generally occurs due to unnecessary steps in operation process such as interaction between various subcontractors and specialist, using excessive quantities of materials than the required, multiple inspection and approval steps, double handling, double checking, and excessive coordination required between suppliers (GulPolat, 2004; El-Kourd, 2009).

V. Motion

The unnecessary and excess moving of manpower, which does not add any value to work and kill time, is known as motion related waste. This can be due to poor layout of tools, materials, and plants (O'Connor R. S., 2013). Detailed list of factors causing motion related waste includes unnecessary labor movement,poor distribution of materials in site, poor site layout, higher request for information, lack of proper maintained pathways, and difficulty in motion of worker at the site (El-Kourd, 2009).

VI. Waiting

Waiting is considered as delay, therefor refers to the period when the resource (manpower/ machinery) idly sits for unproductive activity due to lack of information, material, decision or access (O'Connor, 2013). Waiting related waste is caused by the following 11 types of factors.

i. Delay in approval drawing (GulPolat, 2004).
ii. Waiting for an approval decision.
iii. Waiting time for change or revise the design.
iv. Identifying the conflict between architectural, structural, plumbing and electrical drawing.
v. Delay in material supply (GulPolat, 2004).
vi. Deficiency in detail about the material properties and dimension in the working drawing (GulPolat, 2004).
vii. Change of design at the last moment (Prof.B.PrakashRao, 2014).
viii. Communication gap between designer and site engineers.
ix. Delays in passing of information to the contractor on products (El-Kourd, 2009).
x. Equipment frequently breakdown (El-Kourd, 2009).
xi. Delay in performing inspections and testing by the consultant engineer.

VII. Overproduction

This type of waste occurs when the operation process continues more than needed. Excess product carries extra inventory costs. Overproduction takes place due to ordering material more than required, wrong purchased, ordering material earlier than required, and over design than required.

How far these factors contribute to the waste generation in construction projects in Bangladesh are examined through survey questionnaire. Findings are presented in Chapter 3.

2.4 Impact of waste on construction projects

In the construction projects, material, human resources, money and machine play a vital role and around 60% to 70% of the project cost account for the material (Meghan, 2011). This pushes the construction project vulnerable to waste generation, which results in a negative impact on construction cost and the economy of the country (Rao, 2014). Waste may also affect the project schedule, profit margin budget, and overall quality of the construction work (Chionye, 2012; (Chua, 2003).

2.4.1 Magnitude of waste

Waste-driven impacts, on the basis of magnitude of waste, can further be explained in terms of materials, cost and time.

Materials:

Bossink (1996), in his research on five house building in the Netherlands, identified the following types of waste with their magnitude as stone tablet (27%) followed by pile (17%), concrete (13%), sand lime elements (11%), roof tile (10%), mortars (8%), packing (7%), sand-lime brick (3%) and others (2%). He further added, all the material waste cost 1% to10% of the of the purchase amount of the materials. Rameezden (2004) in Sri Lanka reported the main material wastage in the construction as sand (25%), lime (20%), cement (14%), bricks (14%), ceramic tiles (10%), timber (10%), rubble (7%), steel (7%), cement blocks (6%), paint (5%) and asbestos sheets (3%). In Hong Kong 5% to10% building materials end up with waste (Poon, 2002), compared to 18% of the total purchase materials in Brazil (Pinto, 1989).

Cost:

Cnudde (1991) found that, the cost of poor quality (non-conformance) in the construction site range between 10% and 20% of the total project cost. In this context, 46% problems we related to design, 22% to construction, and 15% to material supply (ibid). In another study in the USA it was found that the deviation costs averaged 12.4% of the total installed project cost. The percentage of the cost of waste material among the total waste cost, which are illustrated in table 2.1.

Table 2.1 presents cost of waste percentage due to waste

Application of construction materials.	Costs of waste (%).
Sand lime bricks.	3
Mortars.	5
Roof tiles	13
Sand lime elements	8
Concrete	7
Piles	13
Stone tablets	26

Source: (Bossink, 1996).

Time:

Time over run is the common problem in the construction industry. In a study on 708 highway projects of Florida Department of Transportation between 1999 and 2001, it was found that the average time over run was 17% of the original contact time; where 29% project time over run was due to error in plans and modifications, and 34% for change condition (Najaf, 2002). Again Shrestha mentioned in his study, the project with construction cost less than $1 million had lower schedule overrun compared to more than $1 million projects. He also indicates that project cost with more than $5 million had the highest time over run, which was 14.35% more from the actual contact (Shrestha, 2013). In the table 2.2 the source and amount of hour lost per month are illustrated (Chua, 2003).

Table 2.2Amount of man hour lost per month due to waste.

Waste Sources	Average monthly man-hours lost (man-hour)
Design error	20.6
Design change	16.2
Design omission	6.4
Field error	15.6
Waiting for wet days	23.9
Material vendor delay	16.4
Underestimate to the work	13.6
Stock problem	5.6
Equipment used by other crew	52.3
Equipment was spoiled	21.7
Equipment's installation and transportation	20.2
Tools not suitable	41.4
Tools was spoiled	22.2
Instructions	6.5
Inspection	31.8
Drawing's reading	14.0
Crews interference	14.4
Congestion of the site	18.3
Lighting problem	9.7
Worker's no enthusiasm	8.7

Source: (Chua, 2003)

2.5Lean production and waste reduction

Lean is a systematic method to maximize customer value by eliminating waste within a manufacturing or production system. The lean management philosophy derived from the Japanese manufacturing industry, mostly from the Toyota Production System (TPS) by Ohno, a young Engineer in Toyota (Holweg 2007). This system (TPS) was introduced after World War II when Japan required producing small batches of cars in many varieties in contrary to the Ford Principle of mass production (same cars with large production runs) (Conte 2002). Toyota concluded that the principle of mass production was not efficient anymore, especially, after the collapse in sales that Toyota encountered and led to releasing large number of its workforce. In response, they came up with new ideas and introduced the Toyota Production system, known as 'lean production' (Ahrens 2006). Toyoto's main purpose behind introducing this new concept was to enhance production efficiency by producing high quality products with maximum value and at less cost (Jacobs, 2010). The system was based on achieving a continuous production flow in order to reduce inventories. In essence, this was accompanied by eliminating activities that add no value to the final product, namely wastes that gave Toyota high performance levels (Conte, 2002). In lean manufacturing, all the lean techniques are employed to continuously identify and remove the wastes from the system (Badurdeen, 2006). Lean production system aims to meet customer requirements by delivering the product instantly and with no intermediate inventories (A. Howell, 1999).The manufacturing process has seen noticeable improvements and development after applying lean production principles to the industry (Zimmer 2005). In 1990 James Womack write a book called "The machine that changed the words" add a new phrase for this production system which is commonly known as "lean manufacturing" (El-Kourd, 2009). The underlying goals of lean are:

I. Eliminate the non-value adding activity
II. Improve response time to customer
III. Benchmarks
IV. Reduction of inventories
V. Improvement of productivity
VI. Increase the flexibility of productions (Desale, 2013).

Although this lean concept was developed for manufacturing industries, this idea is used in construction industries too (Desale, 2013).

The industry has adapted this production model as a means for improving its performance and reducing the waste that tends to exist in the construction industry. Lean production focuses on the reduction of waste, increase of value to the owners, and continuous improvement. Several of these lean production concepts and techniques have been successfully implemented in the construction industry from which effective lean construction tools, such as the Last Planner System, have been developed (Antillon, 2010).

Lean construction has been defined in several ways such as "Lean construction is the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and pursuing perfection in the execution of a constructed project" (Diekmann, 2004). Ahmed and Forbes (2011) and Koskela (2002) described lean construction as “a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value for the customer (both internal and external).” (p. 45).

2.5.1 Lean construction principles

A growing number of construction firms are embracing the Lean methodology that emphasizes maximizing value for the customer while minimizing waste. There are a number of tools including the Last Planner System, Integrated Project Delivery, Building Information Modeling, 5s, and Kaizen Events that can be used in combination to achieve lean. This gives practitioners a wide range of options that can be applied to each project. A number of guiding principles help firms achieve lower costs, reduced construction times, more productivity and efficient project management. They represent a holistic approach to the construction process. Womack and Jonas (1996) describe five lean principles applied by any organization.

I. Specify value

Value is the thing that the customer willing to pay for it. So it is very important to clearly define the value of the product or service as per the customer requirement for all the stakeholders involved in the project (Swefie, 2013). The traditional approach to construction focuses on what the customer wants you to build – what is included in the plans and specifications. Lean construction, in contrast, recognizes that what the customer values is deeper. It is not just about what to build, rather why to build. Correct understanding of the value from the customer’s point of view requires a different level of trust, established early in the planning phases of a project. Lean construction brings together all stakeholders including the owner, architect, engineers, general contractor, subcontractors, and suppliers. The project team not only delivers what the client wants, rather they provide advice and help shape expectations throughout the project.

II. Identify and map the value stream

Once you have a clear understanding of value from the customer’s point of view, you can lay out all of the processes necessary to deliver that value. This is called the value stream.

For each activity, the necessary labor, information, equipment, and materials are defined. Any steps or resources that do not add value are removed.

III. Flows

The third principle is the appropriate flow where the service or works never disturbs in the construction process by eliminating non value adding activity (Womack, 1996). Usually two types of flows in construction process are observed namely, material process and work process. Material process is the continuous flow of material to the site. It includes also processing and assembling on site. The work process ensures best sequence of works on site; however, work process is closely associated with the material process (Koskela, 1992).

IV. Pull

Creating reliable workflows depends on work being released based on downstream demand. Lean construction recognizes that this is best done by those performing the work, often subcontractors. Participants communicate and collaborate closely with each other to determine the schedule of tasks.

V. Perfection

It means delivering a product according to customers need and expectation within agreed time and without any defect. It indicates the continuous improvement of the performance by implementing appropriate methods in the process. Table 2.3 presents summaries of lean principles and their scopes.

Table 2.3: Summarized principles and scope of lean construction

No	Main principles	Scopes
1	Identify Value from the customer's point of view	Increase the value of the product/service through systematic thought of costumer's necessities.
2	Identify and map the value stream.	Introduce continual improvement of the process
		Increase the transparency of the process.
		Focus control of the complete process.
		Balance improvements in flow and conversions
3	Continuous reliable flow by eliminating waste.	Reduce variability in construction process.
		Reduce the proportion of activities that do not add value.
		Reduce cycle time.
		Simplify things through reduction of stages/steps and components increase flexibility in output or final product.
		Increase flexibility/adaptability in output or final product.
4	Pull approach/planning	Producing or supplying as per need/demand.
		Making a working plan agreeing to final individual , who is responsible for the execution of that action/activity.
5	Perfection.	Continuous improvement.
		Carry out benchmarking.

2.5.2 Lean tools and techniques

There are a number of lean tools and techniques, adopted from Toyota and different lean practitioners so as to extend the value and eliminate the waste through design and production. Table 2.4 presents the list of common lean tools and technology uses in the construction sector.

Table 2.4: List of lean tools and technology.

Lean tools	Technology (application of tools)
Collaborative Planning	Reduce inventory
Last planner	Pull scheduling approach
Just-in-Time	Pull approach.
Huddle meetings	Start of the day meeting
First-run studies	Plan Do Check Act
Five S	Visualize production methods
Value stream mapping	VA, NV, ENVA activity
5 Why	Root cause analysis.
Visual Management	Visualize production process
Target value design	Design on the basis of estimation.
Standardization of Productivity	Continuous improvement.
Reduce variability	Get quality right the first time (reduce product variability)
Increase flexibility	Reduce changeover times Use multi skilled teams
Reduce batch size	Focus on improving the upstream flow variability (reduce production variability)
Reduce cycle times	Reduce production cycle durations
Use reliable technology	(E.g. BIM)

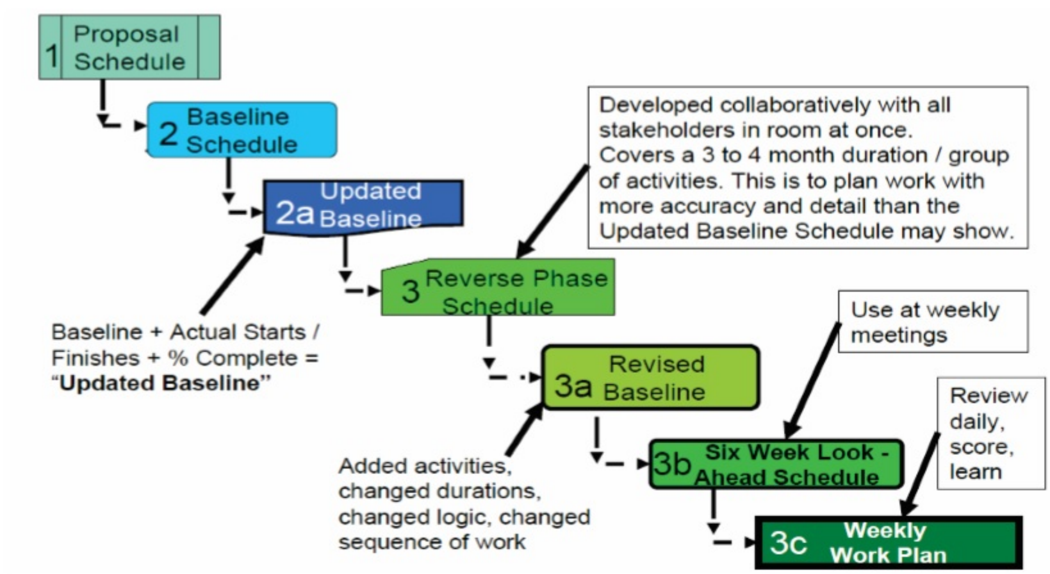
Source: Swefie, 2013; Salem, Solomon, Genaidy, & and Minkarah, 2006; Australia, 2012

In this study, the following lean tools are discussed with illustrations.

- ***Last planner system (LPS):***

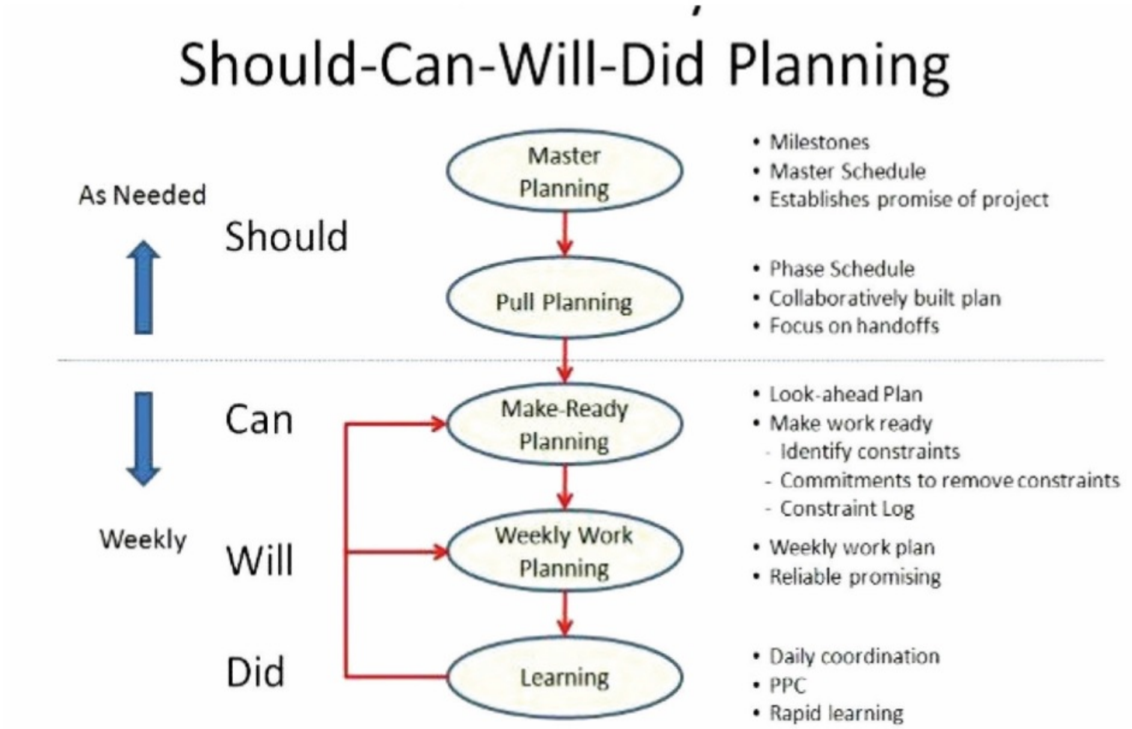
It is one of the associated techniques to the pull approach as it supports the predictability and reliability of construction production in which look-ahead scheduling are adopted. The last planner is simply the field supervisor who assigns work to the crew as it allows the conversations between the site management and the trade foreman at proper level of detail preventing critical issues on site to happen. LPS is a collaborative approach to manage project-based production of complex and uncertain projects, allowing problems to be identified and resolved at the source to increase the chance that work flows with no delays (Mossman, 2012). The LPS practices in construction include managing tender process, design process, and both design and construction production in the context of integrated project delivery (Mossman, 2012). Figure 2.1 shows the Last Planner System procedures. It includes Reverse Phase Scheduling, Six week Look-ahead schedule, weekly work plan and Percentage Plan Completed Charts (PPC). It consists of series of planned conversations as shown in Figure 2. 2.

Figure 2.1: Last Planner System



Source: Zettel 2008

Figure 2.2: Last Planner System conversations



Source: Australia, 2012

- ***The 5s Process***

The 5S method is taken into account among the primary steps that a company ought to absorb implementing the LC philosophy. 5s provide a structured method for achieving, maintaining and improving the standard set-up organization and layout of a work area in order to ensure efficient operation with minimum waste (Neil Kavanagh, 2012). 5s is a short name of five different words, which is described as follows.

a. Sort

Separate the items that are necessary for the process or activity from the unnecessary activity by referencing and placing. Further, it is to eliminate all theunnecessary thing or activity from construction sites (O'Connor R. S., 2013).

b. Straighten or set

The main idea is “a place for everything and everything in its place." Define the location for each essential item and set the layout for a work area, including the proper location for material, plant and equipment (O’Connor, 2013). For proper visualization sign posting, labeling, minimum/ maximum levels, numbering and color coding can be done (Kavanagh, 2012).

c. Shine

The next step is to keep the working site clean and tidy. Ensure tools and machineries are clean and in good working order (O’Connor, 2013). This can be done by encouraging workers after the end of each activity.

d. Standardize

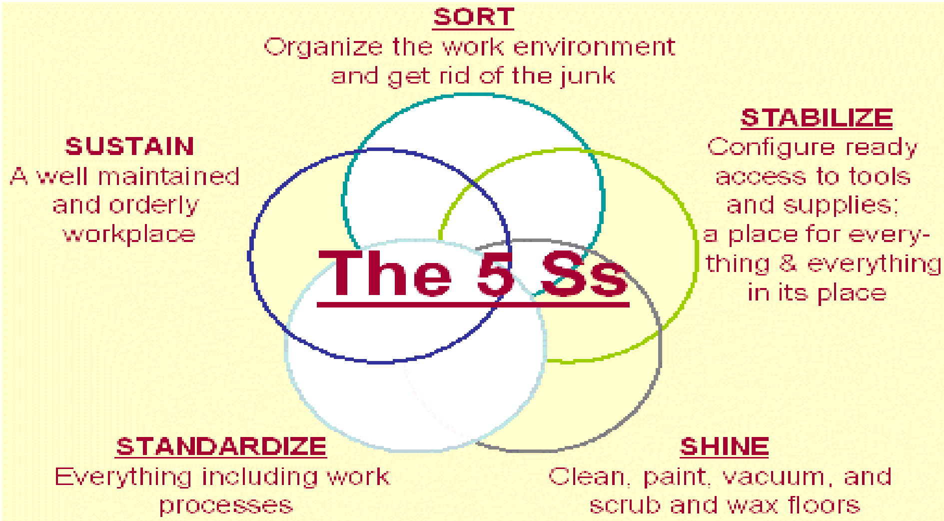
Set the standard rules for work activity such as cleaning, material storage, layout for moving and make it visible for everyone on the site. It will be helpful for eliminating material storage related confusion, also reduce crane movement and walking distance of the crew (Kavanagh, 2012).

e. Sustain

Maintain all the 4s practice throughout the project, for all the employees and workers. Sustain can be done by regular training, audit and consistent application (O’Connor R. S., 2013).

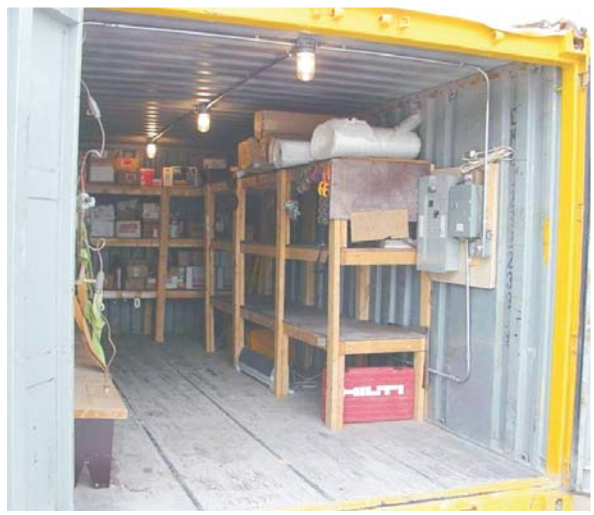
5S system outline is illustrated in Figure 2.3 and its application is shown in Figure 2.4.

Figure 2.3: 5S system outline



Source: Compiled

Figure 2.4: After and before applying5S

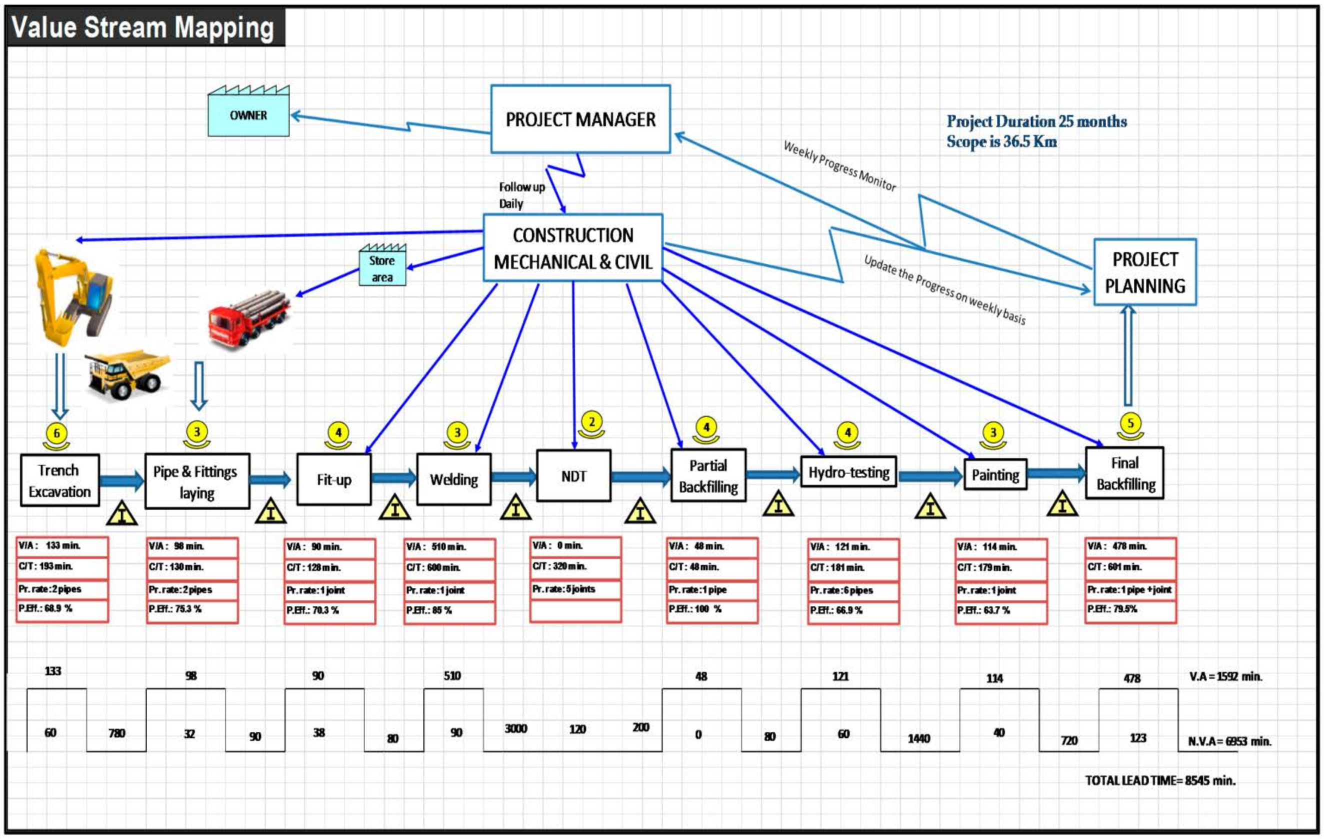


Source: (O'Connor R. S., 2013).

- ***Value stream mapping (VSM)***

Value stream mapping is another lean technique sometimes used for research and to design the flow of materials and knowledge required to deliver a product, service or project to the client (O'Connor, 2013). In this mapping all the actions valueadded or non-value added activity is mapped, as well as the assembly flow of raw material into the arms of the customer. VSM primarily focuses on data management and transformation tasks and therefore the process takes some time and plenty of effort to finish. Figure 2.5 shows the sample of value stream mapping. VSM is suitable for high value projects and where construction activities repeat from one project to another.

Figure 2.5: Sample of value stream mapping of a pipe line construction project

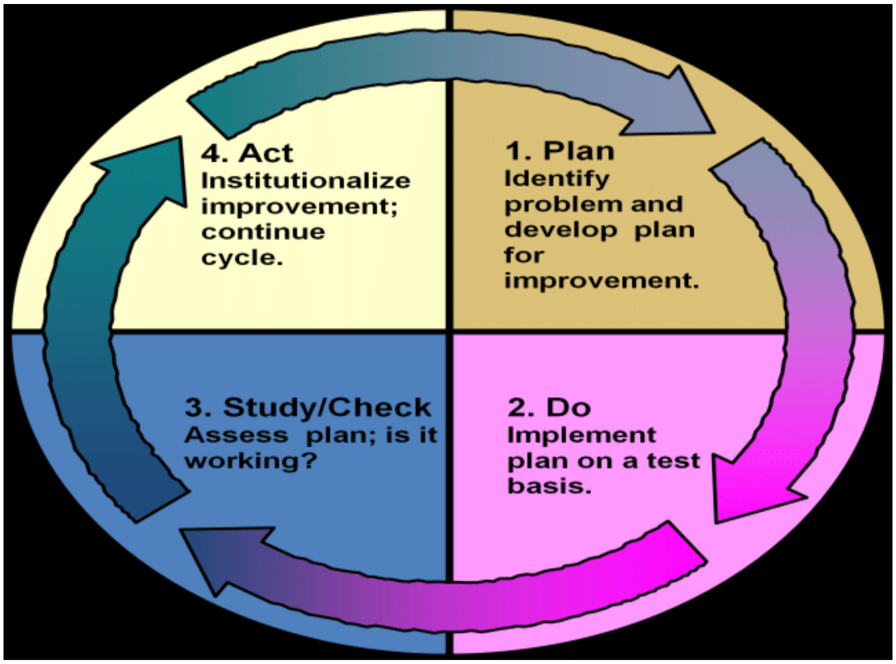


Source: Gunduz and Naser, 2017

- ***First Run Studies:***

"First run studies" aims at continuous improvement by redesigning the production method in order to enhance the quality. This can be a collaborative approach between planner, engineer, contractor and even foreman. The study or method unremarkably uses video file, picture or graphics for the explanation. It consists of four step plan, do, check and act (Salem, Solomon, Genaidy, & and Minkarah, 2006). Figure 2.6 explains the step by step process in first run studies.

Figure 2.6: Step by step process in first run studies



Source: (S. N. Teli, Dec 2012)

- ***Standardization of Productivity:***

The productivity is one in all the vital factors within the construction process. It is the measure of what proportion a labor or machine produces per unit. Its aim is to extend the productivity rate by permitting project participants in understanding the particular production demand. Higher productivity usually results in lower cost, shorter duration and higher rate of return. The formula for measuring productivity is:

Partial Productivity = Total Output / (1) Input

Labor Productivity =Total Output / Number of labor

Material Productivity = Total Output / Amount of Material

Machine Productivity = Value of production / Amount of work

Source: El-Kourd, 2009

- ***Collaborative Planning***

This technique depends on transferal along representatives from all parties involved in construction project to collectively develop a united target program. It can be used at any purpose within the life cycle of a project to recover any time or cost overrun which will occur. It contains 5 steps:

a. High-level collaborative master target program
b. Detailed level collaborative master target program
c. Short-term detailed production plan
d. Daily brief
e. Weekly production control

- ***Just in Time***

Just in times is another lean tool related to pull approach. It means that producing or providing solely what is needed and when it is needed so as to fulfill customer's desires. It reduces inessential inventories or area, increase human productivity, higher equipment productivity and utilization.

- ***Huddle Meetings***

Huddle meeting is another effective lean tool that aims to often organize meeting between employees or foreman in order to cut back communication gap and increase the involvement of the employees. Usually two types of meeting are common:

All foreman meetings:

An informal meeting, with the entire project foreman conducted on a weekly basis. That primarily concentrates on the completion of assignments throughout the subsequent weeks. The discussion throughout the meeting is incredibly effective to spot the overlapping activities and every one others potential issues on the working site. Action agreed at the meeting were recorded and were reviewed the next week (Salem, Solomon, Genaidy, & and Minkarah, 2006).

The start of the day meeting:

Project personal meets at the beginning of each working day for 5 to 10 minutes in order to review the work to be done that day. Scheduling, safety and housekeeping were the most common topics in this meeting (Salem, Solomon, Genaidy, & and Minkarah, 2006).

- ***"5 why"***

"5 why" could be a problem resolution technique to support lean construction in identifying the root causes of an issue fairly quickly. It is the technique of continual asking project participants so as to spot the root cause.

2.5.3 Benefits of Lean Construction

The philosophy of lean construction rests on reducing waste by the application of lean principles and techniques. Bernstein (2013) observed the following benefits from using Lean Construction:

I. Greater profitability / reduce cost.
II. Greater ability for supervisory staff to focus on managing workers.
III. Improve safety.
IV. Higher quality construction.
V. Greater reliability.
VI. Greater customer satisfaction.
VII. Reduced project schedule.
VIII. Greater productivity.
IX. Better risk management across projects

In order to improve construction project many companies try to implement lean construction technique in their organization. Table 2.5 presents some successful implementation of lean tools used in construction sectors.

Table 2.5: Benefits of using lean tools

Case study	Lean tools used	Benefit after implementation of lean tools.	Reference
Bridge construction (Rebar)	• Just-in-time • Prefabrication • Standardization	The overall time and cost decreased from the actual estimation.	Simonsson, Björnfot, Erikshammar, &Olofsson, 2012
Construction of 4 story garage (R.C.C structure)	• Last planner system. • Daily Huddle Meetings • Visual Workplace (5S)	The project was three week onward of the actual schedule and also under budget.	Salem, Solomon, Genaidy, & and Minkarah, 2006
G+28 story residential building in India	• Value stream mapping	The project was finished 56 days earlier than actual schedule.	Desai, 2014
Four 8-Story residential projects in Dahej, Gujarat(R.C.C structure)	• Last planner system. • Value stream mapping	The project was 2 month delay from the actual schedule. After implementation of lean tools the project finally achieves its milestone in schedule time.	Vaidyanathan, 2014)
Construction of housing units by Yobe State public project Nigeria	• Increased visualization • Daily Huddle Meetings	Highly impacted project performance.	Adamu, 2012
Hotel project near downtown in Cairo, Egypt	• Value stream mapping • Just in time. • Last planner system. • BIM. • Standardization.	Able to increase the productivity and reduce the timeline from the actual time.	Swefie, 2013
Infrastructure tunneling project	• Standardization • 5S • Value stream mapping	After implementing lean concept the productivity increase 43% and the project was in time.	Wodalski& Thompson, 2011

Chapter 3:Questionnaire

The previous Chapter, based on review of literature, provided a detailed description about waste, causes of waste generation, and use of various tools and techniques including Lean Production to reduce waste in construction projects. On these aspects, this Chapter presents Bangladesh case with particular reference to Public Works Department through describing the results from questionnaire survey. The questionnaire survey was to find out the main factors impacting the construction projects performance and the employees 'understanding regarding the lean techniques in the construction projects.

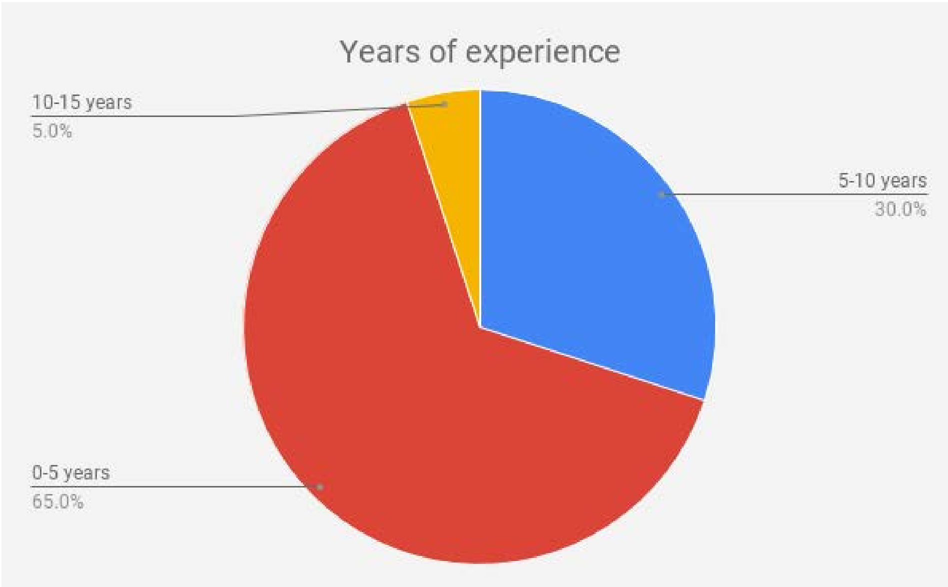
3.1 Results and Findings

At first author of this study has created a questionnaire in Google platform then select 25 professionals from PWD as respondent. After selection of the respondent, author sent them questionnaire link through social media (i.e. Facebook) or email. As stated in Section 1.5, out of 25 AEs and SDEs of the PWD. 20 respondents returned filled-out questionnaire. The following sub-sections presents the findings on various aspects of waste generation, causes and Lean Construction based on the responses of these 20 Assistant Engineers and Sub-Division Engineers of the PWD.

3.2 Profile of respondents

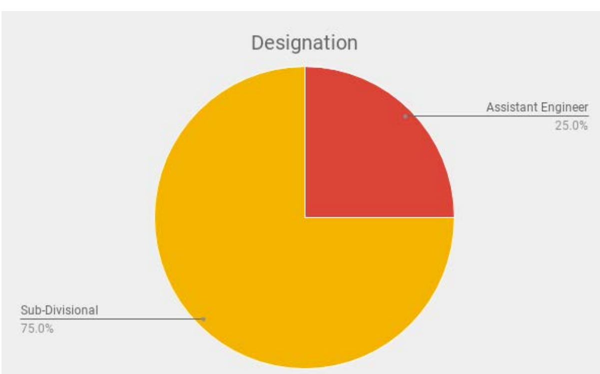
In the beginning, the respondents were asked to provide information about their personal details such as name, employment status, designations, education level and years of experience. It was revealed that the experience of the respondents varied between 5 years and 15 as illustrated in Figure 3.1. Among them, 65% of the surveyed engineers had up to 5 years professional experience in field.

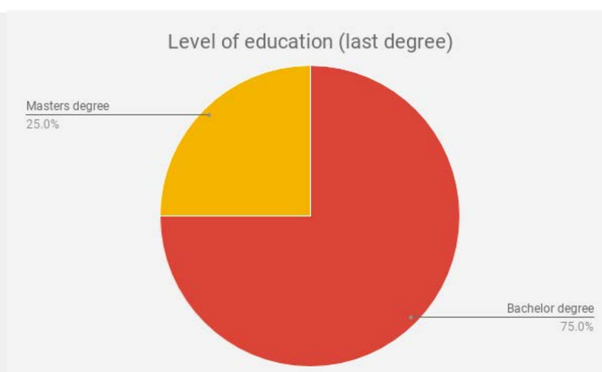
Figure 3.1: Years of experience of the respondents



It was further revealed that three-fourth of the respondents was Sub-Divisional Engineer (SDE) and the remaining was Assistant Engineer (AE) as shown in Figure3.2. Similarly, 75% of the respondents had bachelor degree holder compared to 25% engineers having master's degree (Figure 3.3).

Figure 3.2: Respondents' formal positions Figure 3.3: Respondents' educational levels





3.3 Waste types, waste generation levels and root causes of waste in PWD's construction projects

In Section B of the questionnaire, the survey participants were asked about the possible types of waste generated in construction projects, overall waste generation in percentage in PWD's Construction projects and rank the root causes according to influence in generating waste. The engineers were also asked about rating the role of construction materials (i.e. cement, tiles, paints, pipe, steel, sand, stone chips and bricks) in waste generation in construction projects in percentage.

3.3.1Types of waste in PWD's construction projects

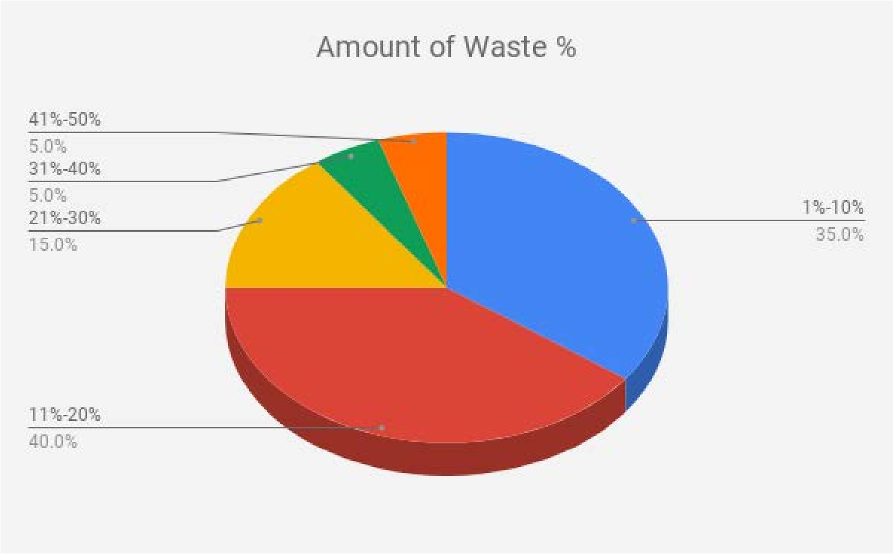
The respondents of the survey reported the following types of waste generated in PWD's construction projects. These types of waste are also observed in any construction project in word as described in Section 2.

- Rework/defect (waste due to scrap and fixing mistake)
- Inventory/Queue (waste due to excessive inventory)
- Transportation (waste due to unnecessary material movement)
- Motion (waste due to unnecessary movement)
- Waiting (time waste due to processing time)
- Over-production (waste due to produce more than needed) and
- Over processing (waste due to excessive processing)

3.3.2 Amount of waste in PWD's construction projects

The highest 40% of respondents reported the existence of 11% to 20% waste in PWD's construction, followed by 35% respondents reporting 1% to 10% waste. However, the highest amount of waste was 41% to 50% waste, said 5% of the respondents. Figure 3.4 shows the details.

Figure 3.4: Percentage of waste in PWD's construction



3.3.3 Influence of root causes of waste in PWD's construction projects

Respondents were presented the root causes of various types of waste (which were identified based on literature review) in the questionnaire and were asked to rate the influence of these factors in waste generation in PWD's projects. Mean value of the respondents' responses were calculated to rank the factors. Table 3.1 to 3.7 presents the ranking of the root causes of waste calculated on the basis of mean value on seven categories of waste.

Table 3.1: Ranking root causes of waste (rework/ defect)

Category	Factors	Mean	Ranking
Rework/ Defect	Lack of workers skill	3.50	1
	Lack of interaction between labor and engineer	3.20	2
	Use of wrong material	3.15	3
	Insufficient instructions about handling	3.10	4
	Labor mistake.	3.00	5
	Choice of wrong construction method	3.00	5
	Imperfect planning of construction	3.00	5
	Damage to work done caused by subsequent trade contractors	2.85	6
	Using faulty construction equipment	2.70	7

Table 3.2: Ranking root causes of waste (inventory/ queue)

Category	Factors	Mean	Ranking
Inventory/ Queue	Poor method of storage facility in site	3.15	1
	Deficiency in detail about the material properties and dimension in the working drawing.	2.75	2
	Damage of material due to deficient stockpiling and handling of material.	2.70	3
	Lack of control on material in the construction site.	2.70	3

Table 3.3: Ranks of root causes of waste (transportation)

Category	Factors	Mean	Ranking
Transportation	Far distance between place of working and storage	2.95	1
	Unpacked supply	2.85	2
	Unnecessary Material Handling and movement	2.80	3
	Use of whatever material very near to work place	2.65	4
	Damage during transportation	2.60	5

Table 3.4: Ranks of root causes of waste (over processing)

Category	Factors	Mean	Ranking
Over processing	Using excessive quantities of materials than the required	2.70	1
	Extra Processing	2.50	2
	Excessive coordination required between suppliers	2.50	2
	Interaction between various stakeholder	2.35	3
	Multiple inspection and approval steps	2.35	3

Table 3.5: Ranks of root causes of waste (motion)

Category	Factors	Mean	Ranking
Motion	Poor distribution of materials in site	2.80	1
	Poor site layout.	2.55	2
	Difficulty in motion of worker in the site	2.45	3
	Lack of proper maintained pathways	2.40	4
	Higher request for information (RFI).	2.30	5
	Unnecessary labor movement	2.30	5

Table 3.6: Ranking of root causes of waste (waiting)

Category	Factors	Mean	Ranking
Waiting	Identifying the conflict between architectural. structural, plumbing and electrical drawing	3.50	1
	Waiting time for change or revise design	3.30	2
	Change of design at the last moment	3.30	2
	Communication gap between designer and site engineers	3.15	3
	Delay in material supply	3.10	4
	Delay in approval drawings	3.05	5
	Deficiency in detail about the material properties and dimension in the working drawing	3.05	5
	Delays in passing of information to the contractor on products	2.85	6
	Waiting for approval decision	2.80	7
	Equipment frequently breakdown	2.80	7
	Delay in performing inspection and/or testing by the consultant engineer	2.65	8

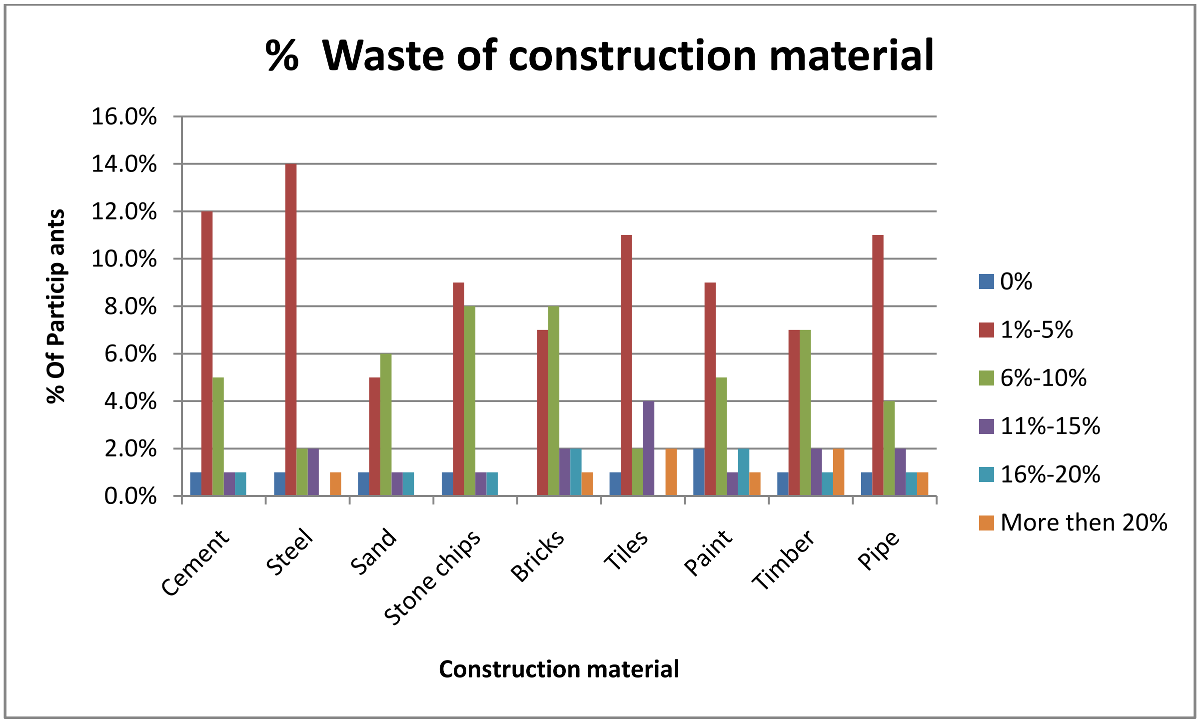
Table 3.7: Ranking root causes of waste (over production).

Category	Factors	Mean	Ranking
Over production	Over design than required	2.70	1
	Wrong purchased due to communication gap	2.60	2
	Ordering material earlier than required	2.50	3
	Ordering material more or less than required	2.35	4

3.3.4 Construction material waste

Figure 3.5 illustrates the percentage of waste resulted from the key construction materials during construction. According to the surveyed respondents, except for sand and bricks, waste from construction materials lies between 1% and 5%. In case of sand, bricks and timber the rate of waste is 6% to 10%.

Figure 3.5: Percentage of waste construction materials



3.4 Impact of waste on construction projects

In this section the participants were asked to identify types of impact due to waste. Furthermore, they were asked to rank the impacts on various aspects of the projects such as time, cost, productivity, quality and profit margin and rate the magnitude of the impacts.

3.4.1 Type of impacts due to waste on construction projects

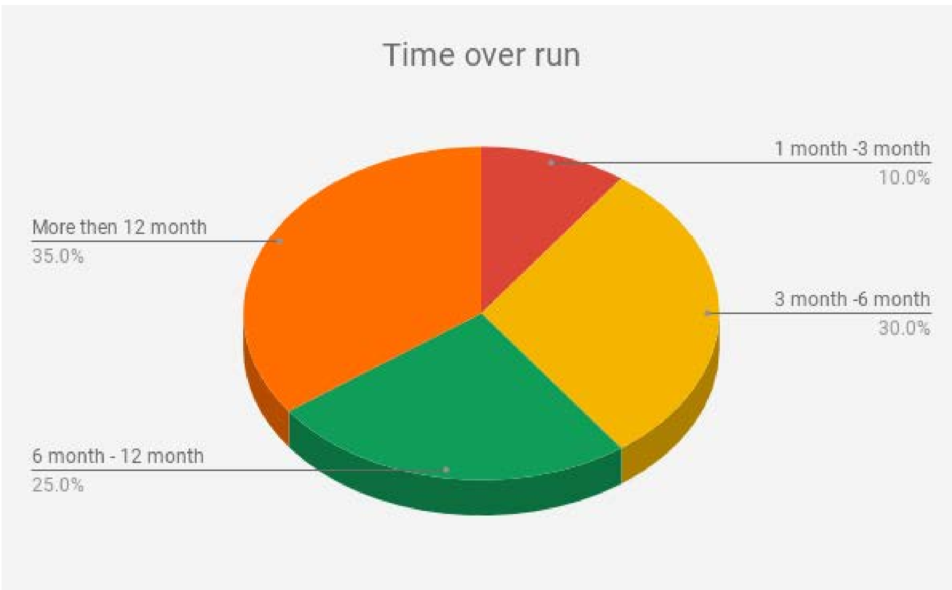
Following are the possible type of impacts caused from waste generation in a construction project, according to most of the participants:

- Time extended to complete project
- Cost increased
- Quality hampered
- Productivity hampered and
- Profit margin narrowed/decreased

3.4.2 Time over run

Figure 3.6 presents the time overrun from the actual schedule. It was revealed that 35 % of the participants reported delay in construction project completion of PWD by more than 12 months compared to 1-3 months delay reported by 10% respondents. It is important to observe that all the surveyed respondents said, PWD's projects were delayed due to waste generated during construction.

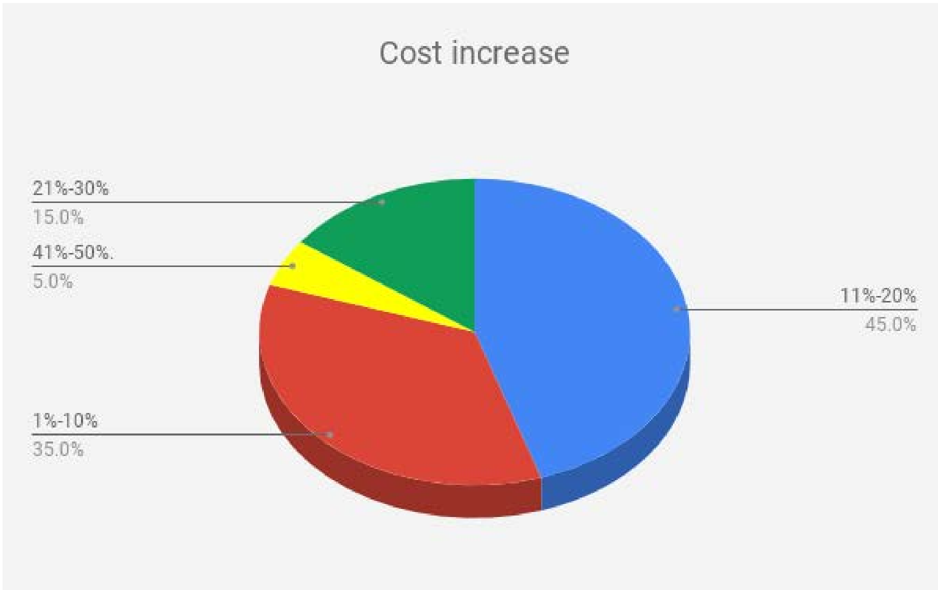
Figure 3.6: Time over run (months) from actual schedule



3.4.3 Cost increase

45% of participants in the survey said, cost increased by 11%-20%from the actual estimation due to waste. An increase in cost between 41 and 50% was reported by 5% respondents. . Figure 3.7 presents cost increase in percentage from the actual estimation due to waste.

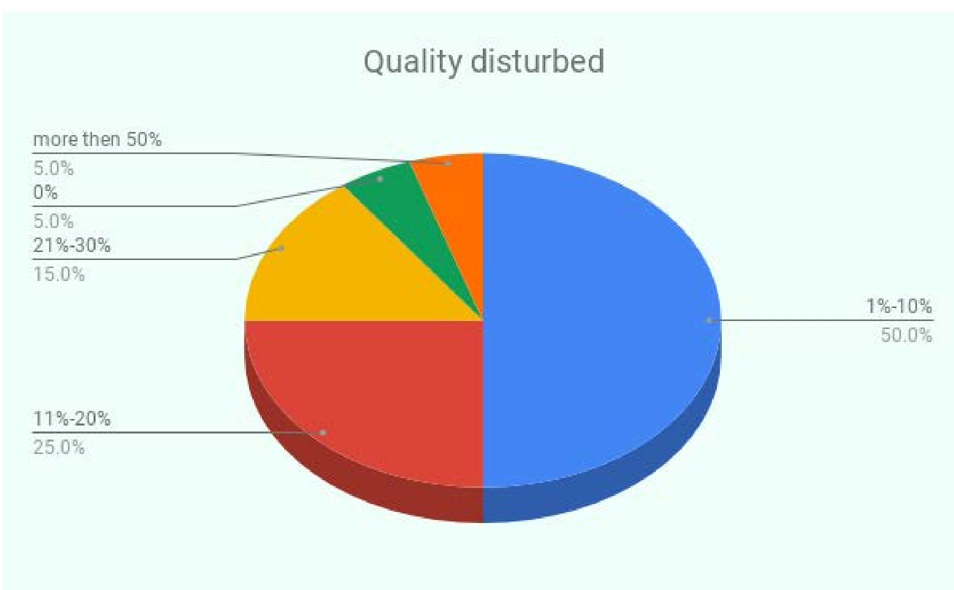
Figure 3.7: Cost increase (percentage) from the actual estimation



3.4.4 Quality disturbed

The quality of work gets disturbed by more than 10% due to waste, said 45% of the survey respondents. The remaining respondents reported 10% or less than 10% disturbance in quality, in which 5% participants reporting zero disturbances.Figure 3.8 shows the details.

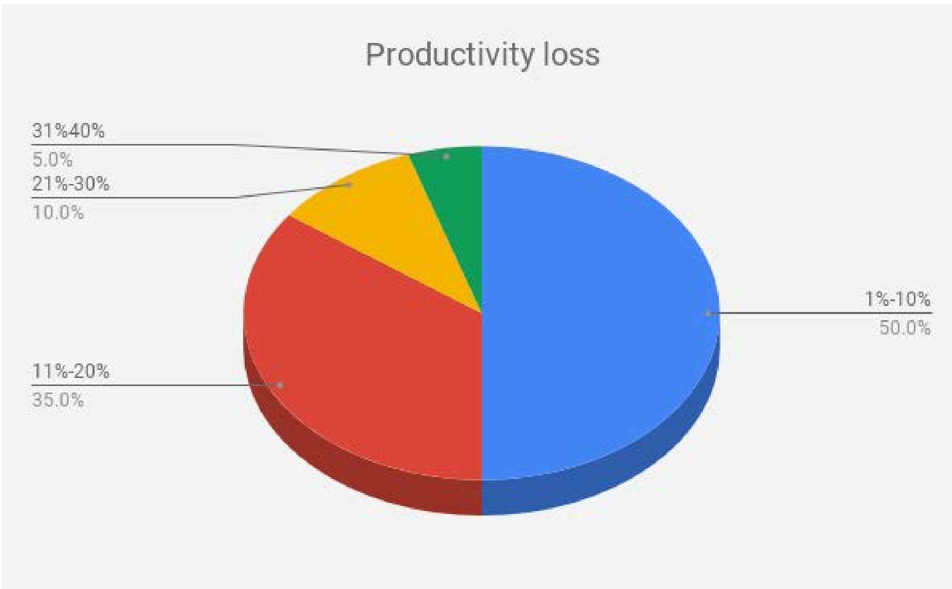
Figure 3.8: Quality disturbed (percentage)



3.4.5 Productivity loss

Figure 3.9 shows the percentage of productivity loss due to waste in construction. Half of the respondents said that waste causes productivity loss by more than 10%. Up to 10% productivity was lost in case of the remaining respondents.

Figure 3.9: Productivity loss (percentage)



3.4.6 Profit margin loss

According to 30% of the respondents, waste causes profit loss by 11-20%. However, the highest percentage of participants in the survey (45%) reported 1%-10% profit lost due to waste and 10% respondents said, waste did not cause profit loss at all. Details are given in Figure 3.10.

Figure 3.10: Profit loss (percentage) due to waste

3.5Knowledge about lean construction

This section tried to understand participants' awareness or knowledge level about lean construction technique and their suitability of application in the PWD's construction projects. In order to improve project performance, 90% participants emphasized the implementation of a new approach or technique.Regarding respondents' awareness about lean construction, 50% of them had average/moderate knowledge, followed by low knowledge reported by 35% of them. Only 5% respondents said that they had very high knowledge about lean construction technique (Figure 3.11).

Figure 3.11: Participants' knowledge about lean construction

To identify the suitability of lean construction in PWDB, participants were asked to rank the effectiveness of lean principles. Mean value was calculated to rank the effectiveness of the lean principles. Table 3.8 presents the detail findings in this regard.

Table 3.8: Rank of lean construction principles and their scope of effectiveness

Lean principles	Scope	Mean	Rank
Identify and focus on customer value	Increase the value of the product/service through systematic consideration of costumer's requirements.	3.00	1
Identify and map the stream.	Introduce continuous improvement of the process.	3.40	1
	Increase the transparency of the process.	3.20	2
	Focus control on the complete process.	3.20	2
	Balance improvements in flow and conversions.	3.20	2
Continuous flow by eliminating waste.	Reduce (cycle) time.	3.25	1
	Reduce the proportion of activities that do not add value.	3.15	2
	Reduce variability in construction process.	3.05	3
	Simplify things through reduction of stages/steps and parts.	3.05	3
	Increase flexibility in construction process.	2.95	4
Pull approach.	Producing or supplying as per need or demand.	3.15	1
	Making a working plan according to last person (Fore man, contractor, etc.) who is responsible for the execution of that activity.	3.05	2
Perfection.	Continuous improvement.	3.35	1
	Carry out Benchmarking.	3.05	2

Chapter 4:Conclusion

This chapter summarize the key findings this study and provides recommendations for future work. At the end, the limitations of this study are described as well.

4.1 Summary of the study

The main goal of this study was to assess the feasibility of applying appropriate techniques like lean construction approach in order boost overall performance of the development project under Public Works Department (PWD), Bangladesh. Accordingly, four research objectives were set at the very beginning of this study. The research objectives were primarily addressed by conducting a literature review and an online based questionnaire survey. Summaries of key findings around research objectives are as follows.

Research Objective 1: To identify the major types of waste in construction projects of PWD, Bangladesh.

Waste is one of the major problems in Bangladesh construction industries. In order to eliminate waste, the first step is to identify the major types of waste. In this study section 2.3.1 & 2.3.2 discussed about the seven types of waste and their root causes. Seven types of waste are inventory, reworks, transportation, over processing, motion, waiting, and overproduction. To present the PWD's construction scenario, a survey was conducted with the participants employed in PWD. According to survey, most of participants agreed upon seven possible types of waste (inventory, reworks, transportation, over processing, motion, waiting, and overproduction) generated in PWD's construction projects. Most of them said that waste exists 11% - 20% in construction projects under PWD. They were also asked to rank the root causes of waste along the magnitude based on their professional experience. Table 3.1 to 3.7 shows the survey results of the root causes of waste. According to participants, following are the main causes of waste generated in a construction project under PWD:

- Lack of workers' skill (rework/defect waste)
- Poor method of storage facility in site (inventory waste)

- Far distance between place of working and storage (transportation waste)
- Using excessive quantities of materials than the required (over processing waste)
- Poor distribution of materials in site (motion waste)
- Identifying the conflict between architectural. structural, plumbing and electrical drawing (waiting waste)
- Over design than required (overproduction waste)

Research objective 2: To measure the effects/impacts of waste in terms of cost, time, quality, productivity and profit during the construction phase.

Waste can affect the overall project performance. This objective was to show the impact of waste on the construction project. Section 2.4 presents the literature review in response to this objective. The survey result gives the opinion of the professionals regarding the type of impacts due to waste and their magnitude. From the survey it was observed that most of the participants identified, as possible types of impact caused from waste generation in a construction project, time extended to complete project, cost increased, quality hampered, productivity hampered and profit margin narrowed/decreased. According to most of the survey participants, the impact of the waste such as time over run from actual schedule of construction project under PWD is more than 12 months (Figure 3.6); cost increase from the actual estimation due to waste is between 11% and20% (Figure 3.7). The respondents also reported construction quality disturbed, productivity loss and profit margin lost due to waste by 1%-10% (figure 3.8, 3.9, 3.10).

Research objective 3: To determine the current appreciation and awareness of Lean Construction among the Engineers of PWD.

In order to improve project performance, 90% participants from the survey put emphasis on the implementation of a new approach or technique. Lean construction is a new approach which embraces a clear set of objectives for the delivery process, aimed toward maximizing performance for the client at the project level, concurrent design, construction, and therefore the application of project management throughout the life cycle of the project from design to delivery. Hence, respondents were asked about their knowledge level regarding lean construction, as lean construction approach or technique is new in Bangladesh. 50% of the participants have average/moderate knowledge, 35% of them have low knowledge, and 10% of respondents have very low knowledge. Only 5% have very high knowledge about lean construction technique (Figure 3.11).

Research objective 4: To assess feasibility of lean construction principles in waste reduction and improvement of overall project performance within PWD.

In order to eliminate waste from the operating process, manufacturing industry invented a new approach known as lean production system. Following the manufacturing industries, construction industries implement this idea within the construction field so as to remove waste that is termed as lean construction. During this study, section 2.5.1 and 2.5.2 represent the literature regarding the lean construction principles and lean construction tools. Womack and Jones give the concept of five basic principles. However, Koskela mentions eleven lean construction principles. To assess the suitability of the lean construction in PWD, the opinion of the professionals were taken through the survey and the findings are given in Table 3.8. Summary of their view on lean principal is given below:

- Identify and focus on customer value (Lean Principal 1): According to participants, under this principle, most effective scope of work is to Increase the value of the product/service through systematic consideration of costumer's requirements.
- Identify and map the stream (Lean Principal 2): most effective scope of work is to introduce continuous improvement of the process.
- Continuous flow by eliminating waste (Lean Principal 3): most effective scope of work is to reduce (cycle) time.
- Pull approach (Lean Principal 4): most effective scope of work is to producing or supplying as per need or demand.
- Perfection (Lean Principal 5): most effective scope of work is continuous improvement.

4.2 Recommendations

According to this study it can be drawn that conventional construction process of PWD causes 11%-20% waste which results from poorly managed systems and process. In order to enhance project performance the following recommendation can be put forward.

- New management approach such as lean construction process can be taken into account in order to reduce waste as the main purpose of lean construction is waste reduction.
- As the implementation of the lean concept still new in this country, literacy of the lean construction should be the first step to understand the benefit of this philosophy. Before applying it to the project, it is recommended to focus on creating awareness among the professionals.
- Public Works Department should arrange different workshops, seminars or training programs for its engineers to make them better understand about the effect of waste and technique for increase productivity.
- More effort should be done to increase the awareness of employees on site about waste reduction and the concern to reduce the non-added value activities should be improved.
- A framework of lean construction delivery system can be developed from this study before practical application.
- Ranking in this study in terms of factors behind waste generation helps the concerned people to undertake initiatives on priority basis to address waste in construction projects.

4.3 Limitations

The study has been carried out with some limitations. Such as, the survey was an online based survey and the numbers of participants is not much. Survey report would be more dependable with large scale participants.Due to online based survey the author has no idea about the reliability of the participant answer. Author couldn't conduct any practical implication/simulation of any lean construction framework due to time constraint and lack of resources.

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Appendix A: Questionnaire and calculation

Addressing the impacts of Waste on overall project performance: Feasibility study of applying Lean construction Principle in Public Works Department (PWD), Bangladesh

Please cooperate me by filling the survey-it should take 20 minutes to complete. The information provided by you will be used for research purposes only and will be treated as confidential.If you have any query or question you can mail me in this address
engr.abid@rocketmail.com

* Required

Section A : Personal Information

1. **1.1 Name of the participant?** *

2. **1.2 The name of the organization working for?** *

3. **1.3 Organization type** *
   Mark only one oval.
   - ◯ Real estate Company
   - ◯ Construction Company
   - ◯ Consultant firm
   - ◯ Government Organization
   - ◯ Other: ____________________

4. **1.4 Designation** *
Mark only one oval.

- Sub-Assistant Engineer
- Assistant Engineer
- Sub-Divisional Engineer
- Executive Engineer
- Designer
- Other: ____________________

5. **1.5 Level of education (last degree)** *
Mark only one oval.

- Diploma
- Bachelor degree
- Masters degree
- Doctorate degree
- Other: ____________________

6. **1.6 Years of experience** *
Mark only one oval.

- 0-5 years
- 5-10 years
- 10-15 years
- 15-20 years
- Other: ____________________

Section B: Causes of waste

7. **2.1 In your view what level of waste is produced on a construction project on an average?** *
Mark only one oval.

- 1%-10%
- 11%-20%
- 21%-30%
- 31%-40%
- 41%-50%
- more then 50%

8. **2.2 What types of waste you think are generated in PWD's construction project? (Multiple response are possible.)** *
Check all that apply.

- [ ] Rework/defect (Waste due to scrap and fixing mistake)
- [ ] Inventory/Queue (Waste due to excessive inventory)
- [ ] Transportation (Waste due to unnecessary material movement)
- [ ] Motion (Waste due to unnecessary movement)
- [ ] Waiting (Time waste due to processing time)
- [ ] Over-production (waste due to produce more then needed)
- [ ] Over processing (Waste due to excessive processing)
- [ ] Other: ____________________

9. **2.3 Below are some construction material.Please rank on a scale of percentage of waste during construction according to your experience. Mark only one oval per row** *

Mark only one oval per row.

	0%	1%-5%	6%-10%	11%-15%	16%-20%	More then 20%
Cement						
Steel						
Sand						
Stone chips						
Bricks						
Tiles						
Paint						
Timber						
Pipe						

Below are the possible type and their causes of construction waste. Please rank on a scale of 1-5 which of these activities is a major contributor of waste generation.

10. **2.4 Type 1: Rework/defect (Waste due to scrap and fixing mistake)** *

Mark only one oval per row.

	Very low influence	low influence	Moderate influence	High influence	Very High influence
labor mistake	⬭	⬭	⬭	⬭	⬭
Insufficient instructions about handling	⬭	⬭	⬭	⬭	⬭
Choice of wrong construction method	⬭	⬭	⬭	⬭	⬭
Damage to work done caused by subsequent trade contractors	⬭	⬭	⬭	⬭	⬭
Using faulty construction equipment	⬭	⬭	⬭	⬭	⬭
Lack of interaction between labor and engineer	⬭	⬭	⬭	⬭	⬭
Imperfect planning of construction	⬭	⬭	⬭	⬭	⬭
Lack of workers skill	⬭	⬭	⬭	⬭	⬭
Use of wrong material	⬭	⬭	⬭	⬭	⬭

11. **2.5 Type 2: Inventory/Queue (Waste due to excessive inventory) Mark only one oval per row** *

Mark only one oval per row.

	Very low influence	low influence	Moderate influence	High influence	Very High influence
Poor method of storage facility in site	⬭	⬭	⬭	⬭	⬭
Lack of control on material in the construction site	⬭	⬭	⬭	⬭	⬭
Damage of material due to deficient stockpiling and handling of material	⬭	⬭	⬭	⬭	⬭
Deficiency in detail about the material properties and dimension in the working drawing	⬭	⬭	⬭	⬭	⬭

12. **2.6 Type 3:Transportation (Waste due to unnecessary material movement) Mark only one oval per row** *

Mark only one oval per row.

	Very low influence	low influence	Moderate influence	High influence	Very High influence
Damage during transportation	◯	◯	◯	◯	◯
Far distance between place of working and storage	◯	◯	◯	◯	◯
Use of whatever material very near to work place	◯	◯	◯	◯	◯
Unpacked supply	◯	◯	◯	◯	◯
Unnecessary Material Handling and movement	◯	◯	◯	◯	◯

13. **2.7 Type 4:Over processing (Waste due to excessive processing) Mark only one oval per row** *

Mark only one oval per row.

	Very low influence	low influence	Moderate influence	High influence	Very High influence
Interaction between various stakeholder	◯	◯	◯	◯	◯
Using excessive quantities of materials than the required	◯	◯	◯	◯	◯
Multiple inspection and approval steps	◯	◯	◯	◯	◯
Extra Processing	◯	◯	◯	◯	◯
Excessive coordination required between suppliers	◯	◯	◯	◯	◯

14. **2.8 Type 5:Motion (Waste due to unnecessary movement) Mark only one oval per row.** *

Mark only one oval per row.

	Very low influence	low influence	Moderate influence	High influence	Very High influence
Unnecessary labor movement	⬭	⬭	⬭	⬭	⬭
Poor distribution of materials in site	⬭	⬭	⬭	⬭	⬭
Poor site layout	⬭	⬭	⬭	⬭	⬭
Higher request for information (RFI)	⬭	⬭	⬭	⬭	⬭
Lack of proper maintained pathways	⬭	⬭	⬭	⬭	⬭
Difficulty in motion of worker in the site	⬭	⬭	⬭	⬭	⬭

15. **2.9 Type 6:Waiting (Time waste due to processing time) Mark only one oval per row** *

Mark only one oval per row.

	Very low influence	low influence	Moderate influence	High influence	Very High influence
Delay in approval drawings	◯	◯	◯	◯	◯
Waiting for approval decision	◯	◯	◯	◯	◯
Waiting time for change or revise design	◯	◯	◯	◯	◯
Identifying the conflict between architectural. structural, plumbing and electrical drawing	◯	◯	◯	◯	◯
Delay in material supply	◯	◯	◯	◯	◯
Deficiency in detail about the material properties and dimension in the working drawing	◯	◯	◯	◯	◯
Change of design at the last moment	◯	◯	◯	◯	◯
Communication gap between designer and site engineers	◯	◯	◯	◯	◯
Delays in passing of information to the contractor on products	◯	◯	◯	◯	◯
Equipment frequently breakdown	◯	◯	◯	◯	◯
Delay in performing inspection and/or testing by the consultant engineer	◯	◯	◯	◯	◯

16. **2.10 Type 7: Over-production (waste due to produce more then needed) Mark only one oval per row** *

Mark only one oval per row.

	Very low influence	low influence	Moderate influence	High influence	Very High influence
Ordering material more or less than required	⬭	⬭	⬭	⬭	⬭
Wrong purchased due to communication gap	⬭	⬭	⬭	⬭	⬭
Ordering material earlier than required	⬭	⬭	⬭	⬭	⬭
Over design than required	⬭	⬭	⬭	⬭	⬭

Section C: Impact on project due to wastage

17. **3.1 What type of impacts you think does waste have on Public Work's project? (Multiple response are possible.)** *

Check all that apply.

- [ ] Time extended to complete project
- [ ] Cost increased
- [ ] Quality hampered
- [ ] Productivity hampered
- [ ] Profit margin narrowed/decreased
- [ ] Other: ____________________

18. **3.2 From your experience average how much extra time required from the estimated schedule time to finish project in Bangladesh ? Mark only one oval**

Mark only one oval.

- In time
- 1 month -3 month
- 3 month -6 month
- 6 month - 12 month
- More then 12 month
- Other: ____________________

19. **3.3 From your experience how much percentage of cost increase from estimated cost in Bangladesh due to waste? Mark only one oval** *

Mark only one oval.

- 0%
- 1%-10%
- 11%-20%
- 21%-30%
- 31%-40%.
- 41%-50%.
- more then 50%

20. **3.4 From your experience how much quality of construction disturbs due to waste? Mark only one oval**

Mark only one oval.

- 0%
- 1%-10%
- 11%-20%
- 21%-30%
- 31%40%
- 41%-50%
- more then 50%

21. **3.5 From your experience how much productivity loss due to waste? Mark only one oval.** *

Mark only one oval.

- 0%
- 1%-10%
- 11%-20%
- 21%-30%
- 31%40%
- 41%-50%
- more then 50%

22. **3.6 From your experience how much profit margin loss due to waste? Mark only one oval.**

Mark only one oval.

- 0%
- 1%-10%
- 11%-20%
- 21%-30%
- 31%40%
- 41%-50%
- more then 50%

Section D:Knowledge of lean construction concept

Click the link below for brief description of lean construction
https://en.wikipedia.org/wiki/Lean_construction

23. **4.1 To improve the overall current situation, the implementation of new techniques/ innovation approaches is required. Mark only one oval.** *

Mark only one oval.

- Agree
- Not agree
- No comments

24. **4.2 Your understanding about lean construction. Mark only one oval.** *

Mark only one oval.

- Very low
- low
- Average
- Very high

Below are the some principle of lean construction and their scope in construction sectors. Please rank on a scale of 1-5 in order to identify effectiveness to remove waste.To learn more about lean construction principle click the following link

http://www.sciencedirect.com/science/article/pii/S111001681300046X

25. **4.5 Principle 1: Identify and focus on customer value Possible tools: Lean Project Delivery (LPD) Mark only one oval per row.**

Mark only one oval per row.

	Not Effective	Less Effective	Effective	Highly effective	Very highly effective
Increase the value of the product/service through systematic consideration of costumers requirements	⬭	⬭	⬭	⬭	⬭

26. **4.6 Principle 2: Identify and map the stream. Possible tools: 5s. Current state map. Future state map. Mark only one oval per row.**

Mark only one oval per row.

	Not Effective	Less Effective	Effective	Highly effective	Very highly effective
Increase the transparency of the process	⬭	⬭	⬭	⬭	⬭
Focus control on the complete process	⬭	⬭	⬭	⬭	⬭
Introduce continuous improvement of the process	⬭	⬭	⬭	⬭	⬭
Balance improvements in flow and conversions	⬭	⬭	⬭	⬭	⬭

27. **4.7 Principle 3: Continuous flow by eliminating waste. Possible tools: 5 why, BIM. Mark only one oval per row.**
Mark only one oval per row.

	Not Effective	Less Effective	Effective	Highly effective	Very highly effective
Reduce the proportion of activities that do not add value	⬭	⬭	⬭	⬭	⬭
Reduce variability in construction process	⬭	⬭	⬭	⬭	⬭
Reduce (cycle) time	⬭	⬭	⬭	⬭	⬭
Simplify things through reduction of stages/steps and parts	⬭	⬭	⬭	⬭	⬭
Increase flexibility in construction process	⬭	⬭	⬭	⬭	⬭

28. **4.8 Principle 4: Pull approach. Possible tools. Last planner, Just in time. Mark only one oval per row.**
Mark only one oval per row.

	Not Effective	Less Effective	Effective	Highly effective	Very highly effective
Producing or supplying as per need or demand	⬭	⬭	⬭	⬭	⬭
Making a working plan according to last person (Fore man, contractor, etc). who is responsible for the execution of that activity	⬭	⬭	⬭	⬭	⬭

29. **4.9 Principle 5: Perfection. Possible tools: 5s, Huddle meeting. Mark only one oval per row.**
Mark only one oval per row.

	Not Effective	Less Effective	Effective	Highly effective	Very highly effective
Continuous improvement	⬭	⬭	⬭	⬭	⬭
Carry out Bench-marking.	⬭	⬭	⬭	⬭	⬭